

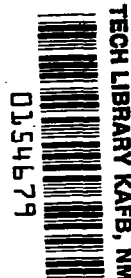
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MARKED INFLUENCE OF CRYSTAL STRUCTURE
ON THE FRICTION AND WEAR CHARACTERISTICS
OF COBALT AND COBALT BASE ALLOYS
IN VACUUM TO 10^{-9} MILLIMETER OF MERCURY
II — COBALT ALLOYS

by Donald H. Buckley and Robert L. Johnson

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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SUMMARY

The friction and wear characteristics of binary tungsten-cobalt and molybdenum-cobalt alloy systems in vacuum (10^{-9} mm Hg) were determined. The influence of the alloying agents on the crystal transformation of cobalt and the friction and wear characteristics of cobalt were determined at varying sliding velocities to 2000 feet per minute. Both rider specimens (3/16-in.-radius hemisphere) and disks ($2\frac{1}{2}$ -in. diameter) were of the same material.

The addition of the alloying elements tungsten and molybdenum influenced the crystal transformation in cobalt. The friction and wear characteristics of hexagonal cobalt were obtained to higher sliding velocities (and therefore higher interface temperatures) with the addition of 32.6 percent tungsten or 25 percent molybdenum; both alloys delayed the transformation of cobalt from the hexagonal to the face-centered-cubic form.

INTRODUCTION

The extremely low ambient pressures and the lack of oxygen in a space environment require a careful selection of metals and alloys for lubrication systems. Materials are desirable which have good friction and wear characteristics, as well as minimum welding tendencies in the absence of surface oxides. Many of the conventionally used lubrication-systems bearing, gear, and seal materials do not possess these characteristics. Some concepts, however, have been developed for the selection of alloys with desirable friction and wear characteristics in the absence of surface oxides. One such concept involves the addition of inclusion compounds to an alloy structure to substitute for the normally present surface films (refs. 1 and 2). Another approach involves the utilization of the duplex structure concept of hard and soft phases (refs. 1 and 2). Further, it has been shown in references 3 and 4 that some of the metals with a hexagonal crystal structure (e.g., cobalt) exhibit much lower friction and wear characteristics in vacuum than similar metals with a cubic structure (nickel or iron).

One difficulty encountered in the use of cobalt alloys for lubrication systems is that cobalt undergoes a crystal transformation from the hexagonal to the face-centered-cubic form at 800° F. Some alloying elements (e.g., nickel) may stabilize the face-centered-cubic form (ref. 5), while others (e.g., molybdenum) in certain concentrations will stabilize the hexagonal crystalline form (ref. 6). With cobalt, friction coefficients of 0.3 were obtained with hexagonal cobalt sliding on hexagonal cobalt, while with the metal in the cubic form, friction coefficients in excess of 1.5 (to complete welding of the specimens) were observed (ref. 4). The wear increased 100 times with the transformation from hexagonal to cubic cobalt. Therefore retention of the hexagonal form of cobalt to as high a temperature as possible is desirable.

This investigation explored the influence of alloying agents on the crystal transformation of cobalt and the resultant effect on friction and wear in vacuum. Friction and wear experiments were conducted in a vacuum of 10^{-9} millimeter of mercury with a hemispherical rider specimen sliding on a flat disk at speeds to 2000 feet per minute.

APPARATUS AND PROCEDURE

The apparatus used in this investigation is shown in figure 1. The basic elements of the apparatus were the specimens (a $2\frac{1}{2}$ -in.-diameter flat disk and a $3/16$ -in.-radius rider) mounted in a vacuum chamber. The disk specimen

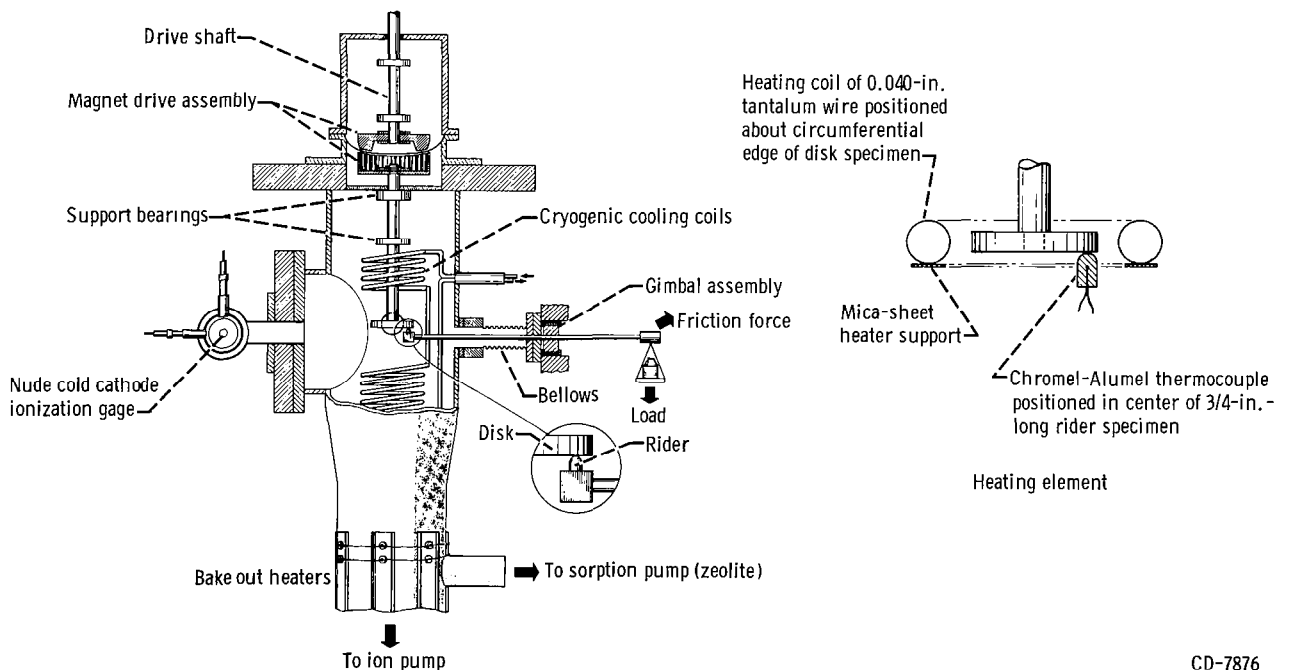


Figure 1. - High-vacuum friction and wear apparatus.

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was driven through a magnetic drive coupling. The coupling had two 20-pole magnets 0.150 inch apart with a 0.030-inch diaphragm between magnet faces. The driver magnet that was outside the vacuum system was coupled to a hydraulic motor. The second magnet was completely covered with a nickel-alloy housing (cutaway in fig. 1) and was mounted on one end of the shaft within the chamber. The end of the shaft that was opposite the magnet contained the disk specimen.

The rider specimen was supported in the specimen chamber by an arm that was mounted by gimbals and bellows to the chamber. A linkage at the end of the retaining arm, away from the rider specimen, was connected to a strain-gage assembly, which was used to measure frictional force. Load was applied through a dead-weight loading system.

Attached to the lower end of the specimen chamber was a 400-liter-per-second ionization pump and a mechanical forepump with liquid-nitrogen cold traps. The pressure in the chamber was measured adjacent to the specimen with a cold-cathode ionization gage. In the same plane as the specimens and ionization gage was a diatron-type mass spectrometer (not shown in fig. 1) for determination of gases present in the vacuum system. A 20-foot-long stainless-steel coil of 3/16-inch diameter was used for liquid-nitrogen and liquid-helium cryopumping of the vacuum system.

SPECIMEN PREPARATION

The cobalt-molybdenum alloys used in this investigation were prepared by charging a zirconium oxide crucible with small 1- by 1- by 1/8-inch electrolytic cobalt chips together with dispersed molybdenum powder. The furnace was evacuated and backfilled with dry argon gas. The charge was melted and the melt poured into a copper mold. The resulting casting was then finished into specimens for friction and wear studies as well as for chemical and metallographic analysis.

With the cobalt-tungsten alloy, three castings were prepared: two, induction melted and a third, arc melted. The induction-melted castings were prepared in the same manner as that employed in the preparation of the cobalt-molybdenum alloys. The arc-cast alloy was prepared by cocompressing powders of both cobalt and tungsten into slugs and then melting with repeated passes in a furnace filled with argon and then evacuated.

The cobalt-tungsten alloy was solution-treated in hydrogen at 2350° F for 1 hour. Later, specimens were aged for 16 hours at 1472° F. Friction data were obtained on both solution-treated alloys and solution-treated alloys which subsequently had been aged. A hardness of Rockwell C-58 was achieved with the cobalt-tungsten alloys after aging.

Specimen Finishing and Cleaning Procedure

The disk and rider specimens used in the friction and wear experiments were finished to a roughness of 4 to 8 microinches. Before each experiment,

the disk and the rider were given the same preparatory treatment: (1) thorough rinsing with acetone to remove oil and grease, (2) polishing with moist levigated alumina on a soft polishing cloth, and (3) thorough rinsing with tap water followed by distilled water. For each experiment, a new set of specimens was used.

RESULTS AND DISCUSSION

Cobalt Sliding on Cobalt

Experiments were conducted in vacuum with cobalt sliding on cobalt (ref. 4) to determine friction characteristics both as a function of sliding velocity and of ambient temperature. The results obtained are presented in figures 2 and 3. Increasing the sliding velocity resulted in an increase in friction coefficient at about 1400 feet per minute (fig. 2). The increase in coefficient of friction at this sliding velocity was attributed to the transformation of cobalt from the hexagonal crystal structure to the face-centered-cubic structure. This transformation is, however, believed to occur only in the rider specimen (ref. 4). At sliding velocities below 1200 feet per minute, a predomi-

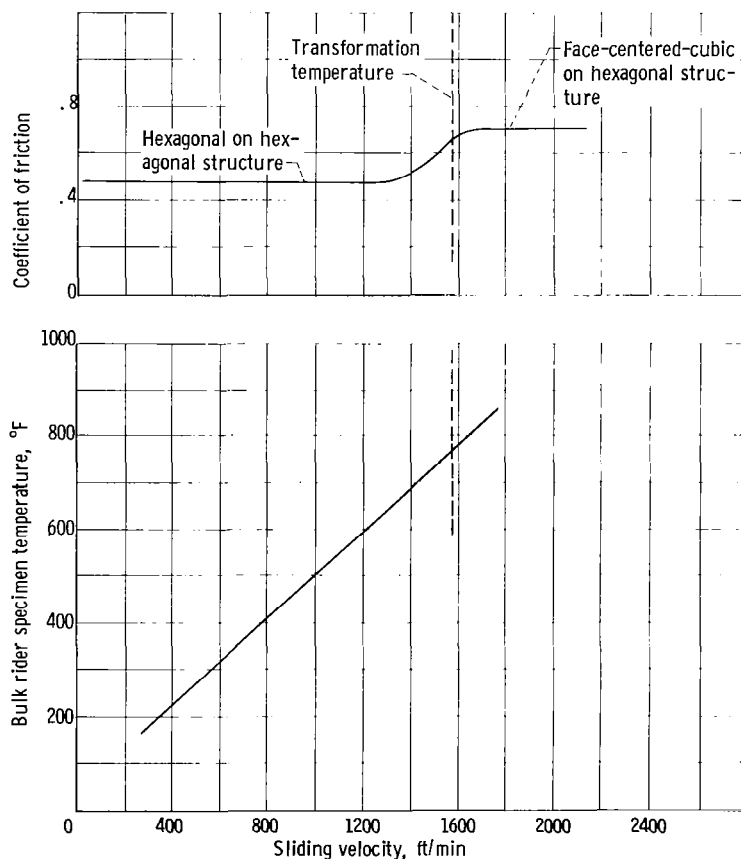


Figure 2. - Coefficient of friction and rider specimen temperatures for cobalt sliding on cobalt at various sliding velocities in vacuum (10^{-9} mm Hg). Load, 1000 grams.

nantly hexagonal crystal form is sliding on a hexagonal crystal form. At sliding velocities in excess of 1500 feet per minute, a predominantly face-centered-cubic structure is sliding on a hexagonal crystal form. Bulk rider specimen temperatures measured during the experiment (fig. 2) were 600° F at 1250 feet per minute and 700° F at 1500 feet per minute. At the higher sliding velocity, the temperature of the rider was in the region associated with the crystal transformation from hexagonal to face-centered-cubic cobalt (734° to 800° F, ref. 4).

Friction data obtained for cobalt sliding on cobalt at various ambient temperatures are presented in figure 3 (from ref. 4). The coefficient of friction for cobalt sliding on cobalt was 0.4 or less at ambient temperatures to 550° F. Above 550° F, the friction coefficient began to increase very

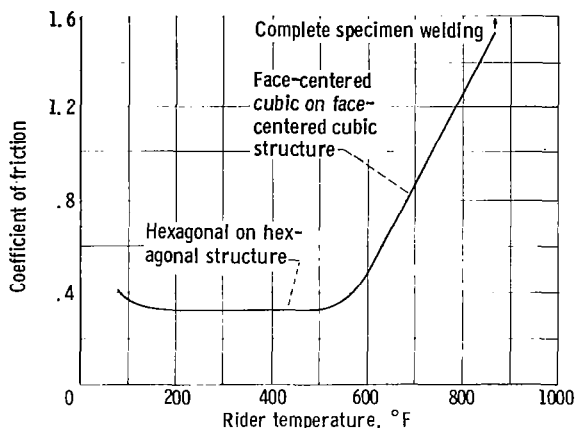


Figure 3. - Coefficient of friction for cobalt sliding on cobalt in vacuum at various rider temperatures. Sliding velocity, 390 feet per minute; load, 1000 grams; ambient pressure, 10^{-8} to 10^{-7} millimeter of mercury.

rapidly. At an ambient temperature of 850° F (above the temperature for crystal transformation) a friction coefficient of 1.45 was recorded; subsequently, complete welding of the disk and the rider specimen occurred. At temperatures below 550° F, the hexagonal crystal structure of cobalt was sliding on the hexagonal crystal structure of cobalt. Above 550° F, the influence of the transformation is observed, with face-centered-cubic cobalt sliding on face-centered-cubic cobalt at 850° F.

Molybdenum-Cobalt Alloys

The crystal transformation temperature of cobalt can be influenced by the presence of alloying elements as indicated in references 5 to 9. In reference 6, it is indicated that the presence of 1 to 2 percent molybdenum in cobalt can shift the crystal transformation temperature of cobalt from 760° to 464° F and the presence of 25 percent molybdenum will inhibit the hexagonal to cubic transformation. Two molybdenum-cobalt alloys that contained nominally 2 and 25 percent molybdenum were therefore prepared. These alloys were cast. Chemical analysis of the compositions revealed that the 25-percent alloy actu-

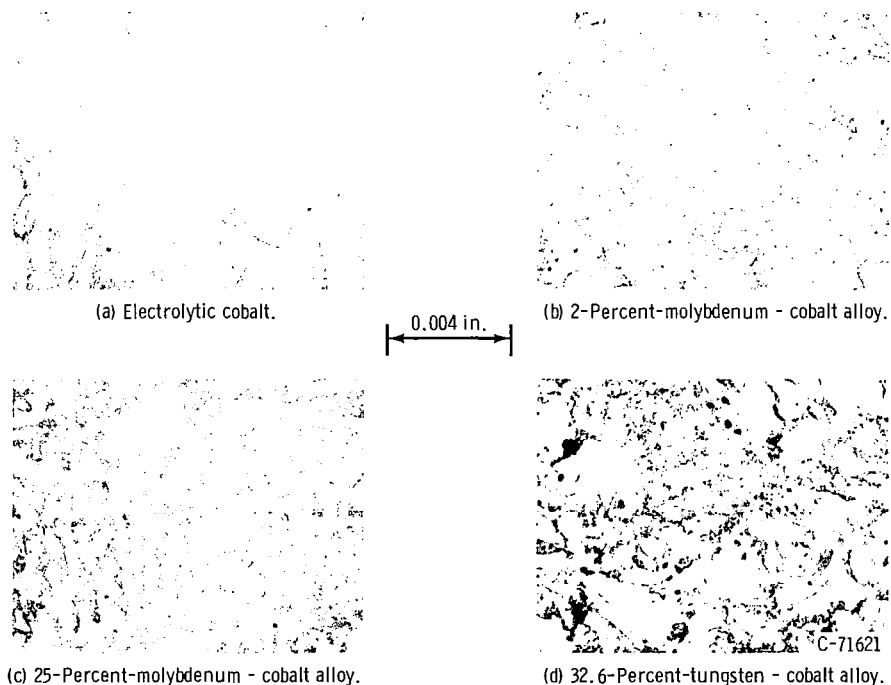


Figure 4. - Photomicrographs of cobalt and cobalt alloys.

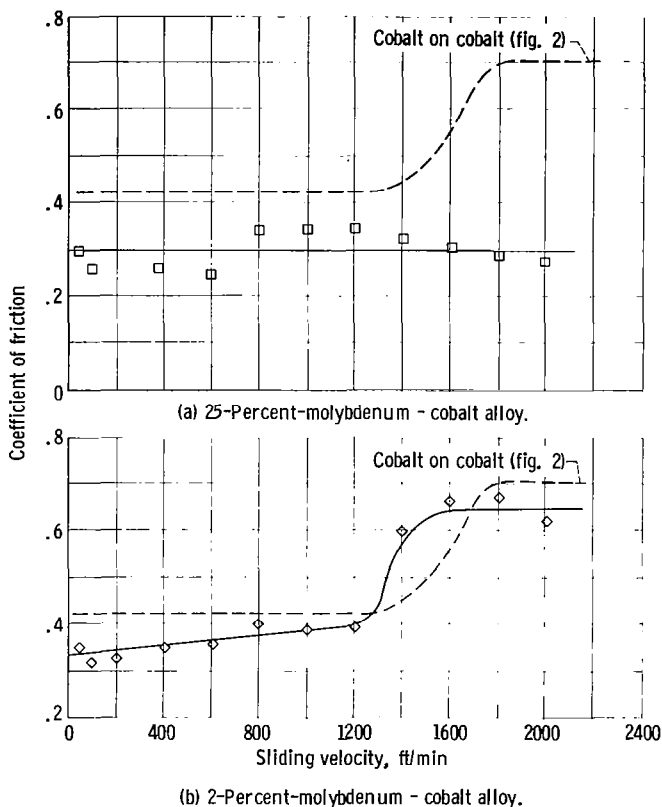


Figure 5. - Coefficient of friction for two molybdenum-cobalt alloys sliding on disks of the same materials in vacuum (10^{-9} mm Hg). Load, 1000 grams; ambient temperature, 75° F.

ally contained 24.4 percent molybdenum and the 2-percent alloy, 2.1 percent molybdenum. Photomicrographs of the structures are presented in figures 4(b) and (c). These alloys are simple solid solutions.

The two molybdenum-cobalt alloys were examined in vacuum friction experiments at various sliding velocities. The results of these experiments are presented in figure 5. With the 25-percent-molybdenum - cobalt alloy (fig. 5(a)), the coefficient of friction remained low (approximately 0.3) at sliding velocities to 2100 feet per minute, well beyond the region where crystal transformation resulted in a marked increase in friction with cobalt sliding on itself. The data would seem to indicate that the desirable friction properties of the hexagonal form of cobalt can be retained by selective alloying.

The friction data obtained with the 2-percent-molybdenum - cobalt alloy are also presented in figure 5. With this alloy, the change in friction was observed at the same sliding velocity as was noted with cobalt sliding on cobalt (fig. 2). It was anticipated that with a 300° F shift in crystal transformation temperature the change in friction would have occurred at a lower sliding velocity. Figure 5(b) suggests that a transformation did take place at a slightly lower temperature for the 2-percent-molybdenum - cobalt alloy than for the unalloyed cobalt.

Cobalt-Tungsten Alloys

Since cobalt in its hexagonal form exhibits low friction and wear properties, the development of alloys which would retain this structure might be interesting, for example, in bearing applications. One requirement for bearing materials in rolling contact is that they be relatively hard (minimum Rockwell hardness of C-58). A cursory examination of phase diagrams indicates that a cobalt-tungsten simple binary solid solution with 35 weight percent tungsten achieves a Rockwell hardness of C-65 on aging. Further, it retains its hardness to relatively high temperatures (fig. 6), exhibiting better hot hardness than most cobalt-base alloys and superior hardness at elevated temperatures to bearing steels. The consideration of a material which does not contain metal

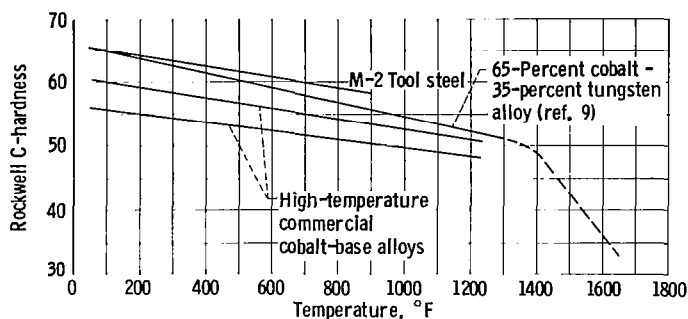


Figure 6. - Hot hardness data for three cobalt-base alloys and bearing steel.

developed from a simple solid solution that has been aged. Friction and wear specimens were prepared from the alloy; a photomicrograph of the final structure after aging is shown in figure 4(d). Although tungsten is soluble in cobalt to 38 ± 2 percent and a simple solid solution was obtained after solution treatment, some Co_3W forms

on aging.

This compound is a hexagonal close-packed structure of the Ni_3Sn type.

Friction data obtained with the alloy at various sliding velocities are presented in figure 7.

In spite of relatively high friction, the surface damage and wear of the alloy were slight, and this alloy may therefore have promise for vacuum applications.

Although the alloy, as reported in reference 8, has a Rockwell hardness of C-65, the final alloy of this investigation contained only 32.6 percent tungsten and the hardness was therefore less, C-58.

This may have an advantage over more conventional bearing alloys because it contains no carbides as hardening agents that are believed to have a detrimental effect on bearing fatigue life.

SUMMARY OF RESULTS

Based on the data obtained in this investigation with cobalt alloys in sliding friction experiments in vacuum, the following summary remarks can be made:

1. The addition of 25 weight percent molybdenum to cobalt inhibited the crystal transformation of cobalt from the hexagonal to cubic form, thereby providing relatively low friction over a greater range of sliding velocities.

2. A simple binary alloy of 32.6 weight percent tungsten in cobalt showed low wear and surface damage in vacuum despite relatively high friction and therefore may offer promise as a bearing material.

Lewis Research Center

National Aeronautics and Space Administration
Cleveland, Ohio, September 21, 1964

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